GUJARAT TECHNOLOGICAL UNIVERSITY

BE-4 SEMESTER – OLD PAPER – S22 TO W25 – Q&A BANK (Numerical)

Subject Name & Code:
Fluid Mechanics (3141906)

Unit 3: Laminar & Turbulent Flow Analysis

(As per new Syllabus For Unit- 6&7 Numerical)

Topic/Formula Group: Chezy's Formula (Friction loss)
Marks Group: 3
Numerical Question:

1. Determine the head lost due to friction in a pipe. Diameter and length of pipe are 250 mm and 60 m respectively. Velocity of flowing water inside pipe = 2.5 m/s. Chezy's constant = 60. Use Chezy's formula $V = C\sqrt{mi}$.
   - **Appeared in:** 3141906(2) (Q5a, 03 marks)
   - **Frequency Tag:** Single/Unique
   - **Input Variables:** D = 250 mm = 0.25 m, L = 60 m, V = 2.5 m/s, C = 60

Answer:

Given:
Diameter $D = 250 \text{ mm} = 0.25 \text{ m}$
Length $L = 60 \text{ m}$
Velocity $V = 2.5 \text{ m/s}$
Chezy's constant $C = 60$
To find: Head lost due to friction h_f
Formula: Chezy's formula: $V = C\sqrt{mi}$
Where hydraulic mean depth $m = D/4$ (for circular pipe), $i = h_f/L$
Solution:

$$m = \frac{D}{4} = \frac{0.25}{4} = 0.0625 \text{ m}$$

$$V = C\sqrt{m \cdot \frac{h_f}{L}} \implies 2.5 = 60\sqrt{0.0625 \times \frac{h_f}{60}}$$

$$\frac{2.5}{60} = \sqrt{0.0625 \times \frac{h_f}{60}}$$

$$0.04167 = \sqrt{0.0625 \times \frac{h_f}{60}}$$

Square both sides:

$$0.001736 = 0.0625 \times \frac{h_f}{60}$$

$$0.001736 = \frac{0.0625h_f}{60}$$
$$0.001736 \times 60 = 0.0625h_f$$
$$0.10416 = 0.0625h_f$$
$$h_f = \frac{0.10416}{0.0625} = 1.666\ \text{m}$$

Final Answer:

$$\boxed{h_f = 1.667\ \text{m}}$$

Topic/Formula Group: Pipe Sizing (Darcy-Weisbach / Friction loss)
Marks Group: 7
Numerical Question:

1. Water is to be supplied to the inhabitants of a college hostel through a supply main. Data: distance = 4000 m; inhabitants = 3000; consumption per inhabitant per day = 180 litres; head loss due to friction = 18 m; friction coefficient $f = 0.007$. Half of the daily supply is pumped in 8 hours. Determine the size of the supply main.
   - **Appeared in:** 3141906(5) (Q3c, 07 marks)
   - **Frequency Tag:** Most Repeated
   - **Input Variables:** L = 4000 m, population = 3000, per capita consumption = 180 L/day, h_f = 18 m, f = 0.007, pumping time = 8 hrs (for half daily supply)

Answer:

Length $L = 4000$ m
Population = 3000, consumption per inhabitant per day = 180 litres
Head loss due to friction $h_f = 18$ m
Friction coefficient $f = 0.007$ (Darcy friction factor)
Half of daily supply pumped in 8 hours.
To find: Size of supply main (diameter D)
Solution:
Step 1 – Daily total supply
Total per day = $3000 \times 180 = 540{,}000$ litres $= 540$ m^3
Step 2 – Pumping rate
Half daily supply = 270 m^3 pumped in 8 hours.
Flow rate $Q = \frac{270}{8\times3600} = \frac{270}{28800} = 0.009375\ \text{m}^3/\text{s} = 9.375$ L/s
Step 3 – Darcy-Weisbach equation

$$h_f = \frac{fLQ^2}{12.1D^5}\text{(for pipe flow, in consistent units)}$$

Actually standard: $h_f = \frac{fL\ ^2}{2gD}$, with $V = \frac{4Q}{\pi D^2}$
Substitute:

$$h_f = \frac{fL}{2gD} \cdot \left(\frac{16Q^2}{\pi^2 D^4}\right) = \frac{8fLQ^2}{g\pi^2 D^5}$$

Using g=9.81, $\pi^2 \approx 9.8696$:

$$h_f = \frac{8fLQ^2}{9.81 \times 9.8696\,D^5} = \frac{8fLQ^2}{96.86\,D^5} \approx \frac{fLQ^2}{12.1\,D^5}$$

So $D^5 = \frac{fLQ^2}{12.1\,h_f}$

Step 4 – Compute

$f = 0.007, L = 4000, Q = 0.009375, h_f = 18$

$Q^2 = 8.789 \times 10^{-5}$

$fLQ^2 = 0.007 \times 4000 \times 8.789 \times 10^{-5} = 28 \times 8.789 \times 10^{-5} = 2.461 \times 10^{-3}$

$D^5 = \frac{2.461 \times 10^{-3}}{12.1 \times 18} = \frac{2.461 \times 10^{-3}}{217.8} = 1.130 \times 10^{-5}$

$D = (1.130 \times 10^{-5})^{1/5}$

$0.1^5 = 1 \times 10^{-5}, 0.11^5 = 1.61 \times 10^{-5}$ → interpolate: D ≈ 0.102 m = 102 mm

Final Answer:

$$\boxed{D \approx 100 \text{ mm (say 100 mm pipe)}}$$

2. Calculate the discharge through a pipe of diameter 250 mm when the difference of pressure head between two ends of a pipe 500 mm apart is 3.5 m of water. Take friction factor = 0.04.
   - **Appeared in:** 3141906(5) (OR Q4b, 07 marks)
   - **Frequency Tag:** Most Repeated
   - **Input Variables:** D = 250 mm, length L = 500 mm (likely a typo – probably 500 m), h_f = 3.5 m water, f = 0.04

Answer:

Given:

Diameter $D = 250$ mm $= 0.25$ m

Length $L = 500$ mm? → Likely typo, should be 500 m. Assume $L = 500$ m

Head loss $h_f = 3.5$ m of water

Friction factor $f = 0.04$

To find: Discharge Q

Solution:

Darcy-Weisbach:

$$h_f = \frac{fLQ^2}{12.1D^5}$$

$$Q^2 = \frac{h_f \times 12.1D^5}{fL}$$

$D^5 = (0.25)^5 = 0.25^2 = 0.0625, \times\, 0.0625 = 0.00390625, \times\, 0.25 = 0.00097656$

$12.1D^5 = 12.1 \times 0.00097656 = 0.011816$

$h_f \times 12.1D^5 = 3.5 \times 0.011816 = 0.041356$

$Q^2 = \frac{0.041356}{0.04 \times 500} = \frac{0.041356}{20} = 0.0020678$

$Q = \sqrt{0.0020678} = 0.04547\ \text{m}^3/\text{s} = 45.47$ L/s

Final Answer:

$$\boxed{Q = 45.5 \text{ L/s}}$$

3. Determine the optimum diameter of a pipe to carry 100 L/s of crude oil (density = 950 $\mathrm{kg/m^3}$, dynamic viscosity = 0.08 $\mathrm{kg/(m \cdot s)}$) and still maintain laminar flow. Also determine the power required for transport over one kilometre distance.
   - **Appeared in:** WIN24 (OR Q4c, 07 marks)
   - **Frequency Tag:** Most Repeated
   - **Input Variables:** Q = 100 L/s = 0.1 m^3/s, ρ = 950 kg/m^3, μ = 0.08 Pa·s, L = 1 km, flow regime = laminar

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Answer:

Given:

$$Q = 100\,\mathrm{L/s} = 0.1\,\mathrm{m^3/s}$$

$\rho = 950\,\mathrm{kg/m^3}$, $\mu = 0.08\,\mathrm{Pa \cdot s}$

$$L = 1\,\mathrm{km} = 1000\,\mathrm{m}$$

Flow regime: laminar

To find: Optimum diameter (maximum possible for laminar?) Actually "optimum diameter" to maintain laminar flow – means find diameter such that Re ≤ 2000 (critical). Then power required.

Solution:

Step 1 – Reynolds number for laminar limit

$$Re = \frac{\rho V D}{\mu} \leq 2000$$

$V = \frac{4Q}{\pi D^2} \rightarrow Re = \frac{4\rho}{\pi \mu D}$

Set Re = 2000:

$$2000 = \frac{4 \times 950 \times 0.1}{\pi \times 0.08 \times D} = \frac{380}{0.2513D} = \frac{1512.5}{D}$$

$$D = \frac{1512.5}{2000} = 0.756\,\mathrm{m}$$

Thus for laminar flow, D must be ≥ 0.756 m (larger D gives lower Re). Optimum = minimum D that keeps laminar? Usually largest possible for laminar is 0.756 m.

Step 2 – Power required

For laminar flow, Hagen-Poiseuille:

$$h_f = \frac{128 \mu L Q}{\pi \rho g D^4}$$

But power $P = \rho g Q h_f = \frac{128\mu \quad ^2}{\pi D^4}$

With D = 0.756 m:

$$D^4 = (0.756)^4 = 0.756^2 = 0.5715, \times 0.5715 = 0.3266$$

$$P = \frac{128 \times 0.08 \times 1000 \times (0.1)^2}{\pi \times 0.3266} = \frac{128 \times 0.08 \times 1000 \times 0.01}{1.026}$$

$$= \frac{102.4}{1.026} = 99.8\,\mathrm{W}$$

Final Answer:

$$\boxed{D_{\mathrm{opt}} = 0.756\,\mathrm{m}, P = 100\,\mathrm{W}}$$

Topic/Formula Group: Flow Between Parallel Plates
Marks Group: 7
Numerical Question:

1. Glycerine of specific gravity 1.28 and viscosity 8.07 poise flows between two large parallel flat plates 1.5 cm apart. The rate of flow is 4.4 m^2/hour per metre width of the plates. Determine: (i) maximum velocity, (ii) maximum shear stress, (iii) pressure gradient, (iv) Reynolds number.
   - **Appeared in:** 3141906 (OR Q3c, 07 marks)
   - **Frequency Tag:** Single/Unique
   - **Input Variables:** SG = 1.28, μ = 8.07 poise = 0.807 Pa·s, gap h = 1.5 cm = 0.015 m, flow rate per unit width = 4.4 m^2/hr = 4.4/3600 m^2/s

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Answer:

Given:

SG = 1.28 → $\rho = 1280\ \text{kg/m}^3$

Viscosity $\mu = 8.07$ poise $= 0.807\ \text{Pa}\cdot\text{s}$

Gap $h = 1.5\ \text{cm} = 0.015\ \text{m}$

Flow rate per unit width $q = 4.4\ \text{m}^2/\text{hour} = 4.4/3600 = 0.001222\ \text{m}^2/\text{s}$

To find: (i) maximum velocity, (ii) maximum shear stress, (iii) pressure gradient, (iv) Reynolds number

Solution for laminar flow between parallel plates (both stationary):

Step 1 – Pressure gradient

For plane Poiseuille flow: $q = \frac{h^3}{12\mu}\left(-\frac{dp}{dx}\right)$

$$-\frac{dp}{dx} = \frac{12\mu q}{h^3} = \frac{12 \times 0.807 \times 0.001222}{(0.015)^3}$$

$$(0.015)^3 = 3.375 \times 10^{-6}$$
$$12 \times 0.807 \times 0.001222 = 12 \times 0.000986 = 0.01183$$
$$-\frac{dp}{dx} = \frac{0.01183}{3.375 \times 10^{-6}} = 3505\ \text{Pa/m}$$

Step 2 – Maximum velocity

$$u_{\text{max}} = \frac{h^2}{8\mu}\left(-\frac{dp}{dx}\right) = \frac{(0.015)^2}{8 \times 0.807} \times 3505 = \frac{0.000225}{6.456} \times 3505 = 3.485 \times 10^{-5} \times 3505 = 0.1222\ \text{m/s}$$

Step 3 – Maximum shear stress

At wall: $\tau_{\text{max}} = \frac{h}{2}\left(-\frac{dp}{dx}\right) = \frac{0.015}{2} \times 3505 = 0.0075 \times 3505 = 26.29\ \text{Pa}$

Step 4 – Reynolds number

Hydraulic diameter $D_h = 2h = 0.03\ \text{m}$

Average velocity $V_{\text{avg}} = q/h = 0.001222/0.015 = 0.08147\ \text{m/s}$

$Re = \frac{\rho V D_h}{\mu} = \frac{1280 \times 0.08147 \times 0.03}{0.807} = \frac{3.128}{0.807} = 3.876$ (laminar)

Final Answer:

$$\boxed{u_{\text{max}} = 0.122\ \text{m/s}, \tau_{\text{max}} = 26.3\ \text{Pa}, -\frac{dp}{dx} = 3505\ \text{Pa/m}, Re = 3.88}$$

Topic/Formula Group: Minor Losses (Contraction)
Marks Group: 7
Numerical Question:

1. A pipe of 150 mm diameter is attached to a 100 mm diameter pipe by means of a flange in the same horizontal axis. Rate of flow is $2\ \mathrm{m^3/min}$ and a manometer shows a pressure difference reading of 80 mm. Find: (i) loss of head due to contraction, (ii) coefficient of contraction.
   - **Appeared in:** 3141906 (Q3c, 07 marks)
   - **Frequency Tag:** Single/Unique
   - **Input Variables:** D1 = 150 mm, D2 = 100 mm, Q = 2 m^3/min = 1/30 m^3/s, manometer reading = 80 mm (fluid unspecified)

Answer:
Given:

$$D_1 = 150\ \mathrm{mm} = 0.15\ \mathrm{m}$$
$$D_2 = 100\ \mathrm{mm} = 0.10\ \mathrm{m}$$
$$Q = 2\ \mathrm{m^3/min} = 2/60 = 0.03333\ \mathrm{m^3/s}$$

Manometer reading (pressure difference) = 80 mm of (fluid unspecified – assume mercury or water? Usually water in manometer, but let's assume water for simplicity; if mercury, convert). Assume manometer fluid = water.
To find: (i) Loss of head due to contraction, (ii) Coefficient of contraction C_c
Solution:
Step 1 – Velocities

$$A_1 = \frac{\pi}{4}(0.15)^2 = 0.01767\ \mathrm{m^2}$$
$$A_2 = \frac{\pi}{4}(0.1)^2 = 0.007854\ \mathrm{m^2}$$
$$V_1 = Q/A_1 = 0.03333/0.01767 = 1.886\ \mathrm{m/s}$$
$$V_2 = Q/A_2 = 0.03333/0.007854 = 4.245\ \mathrm{m/s}$$

Step 2 – Pressure drop from manometer
Manometer reading 80 mm water → $\Delta P = \rho g h = 1000 \times 9.81 \times 0.08 = 784.8\ \mathrm{Pa}$
Head difference = 0.08 m of water.
Step 3 – Loss of head
Apply Bernoulli between section 1 (upstream) and section 2 (downstream in smaller pipe) including loss:

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + h_L$$
$$h_L = \frac{P_1 - P_2}{\rho g} + \frac{V_1^2 - V_2^2}{2g}$$

$\frac{P_1 - P_2}{\rho g} = 0.08$ m (from manometer)

$$\frac{V_1^2 - V_2^2}{2g} = \frac{(1.886)^2 - (4.245)^2}{2 \times 9.81} = \frac{3.556 - 18.02}{19.62} = \frac{-14.464}{19.62} = -0.737\ \mathrm{m}$$

$h_L = 0.08 + (-0.737) = -0.657$ m – negative? That implies pressure drop is not enough to account for velocity increase. Actually for contraction, $P_1 - P_2$ is positive and large. The manometer reading should be in mercury to get a larger head. Let's assume the 80 mm is mercury.

Recalc with mercury: $\frac{P_1 - P_2}{\rho_w g} = x\left(\frac{\rho_m}{\rho_w} - 1\right) = 0.08 \times (13.6 - 1) = 0.08 \times 12.6 =$ 1.008 m of water

Then $h_L = 1.008 - 0.737 = 0.271$ m

Step 4 – Coefficient of contraction

Loss head for sudden contraction: $h_L = \frac{V_2^2}{2g}\left(\frac{1}{C_c} - 1\right)^2$

$$0.271 = \frac{(4.245)^2}{2 \times 9.81}\left(\frac{1}{C_c} - 1\right)^2 = \frac{18.02}{19.62}\left(\frac{1}{C_c} - 1\right)^2 = 0.9185\left(\frac{1}{C_c} - 1\right)^2$$

$$\left(\frac{1}{C_c} - 1\right)^2 = \frac{0.271}{0.9185} = 0.295$$

$$\frac{1}{C_c} - 1 = \sqrt{0.295} = 0.543$$

$$\frac{1}{C_c} = 1.543 \implies C_c = 0.648$$

Final Answer:

$$\boxed{h_L = 0.271 \text{ m water}, C_c = 0.648}$$

Assignment – 3 (Question Related To unit-6&7)

Q-1: Reynolds Number & Flow Regime: Jatropha oil (Specific Gravity = 0.92, dynamic viscosity = 0.035 Pa.s) flows through a 50 mm diameter pipe. Calculate the maximum volumetric flow rate (Q) for which the flow will remain strictly laminar (Assume critical Reynolds number Re = 2000).

Answer:

Given:

SG = 0.92 → $\rho = 920 \text{ kg/m}^3$

$$\mu = 0.035 \text{ Pa} \cdot \text{s}$$
$$D = 50 \text{ mm} = 0.05 \text{ m}$$
$$Re_{crit} = 2000$$

To Find: Max volumetric flow rate Q for laminar flow

Formula:

$Re = \frac{\rho V D}{\mu} = 2000 \rightarrow V = \frac{2000}{\rho D}$

$$Q = V \times \frac{\pi D^2}{4}$$

Solution:

$$V = \frac{2000 \times 0.035}{920 \times 0.05} = \frac{70}{46} = 1.5217 \text{ m/s}$$

$$Q = 1.5217 \times \frac{\pi (0.05)^2}{4} = 1.5217 \times 0.0019635 = 0.002988 \text{ m}^3/\text{s}$$

$$Q \approx 2.99 \text{ lps}$$

Final Answer:

$$\boxed{Q_{max} = 0.00299 \text{ m}^3/\text{s} \approx 3 \text{ lps}}$$

Q-2: Hagen-Poiseuille Flow: For the laminar flow of the Jatropha oil calculated in Question 1, determine the pressure drop over a 15 m length of the horizontal pipe. Also, calculate the maximum velocity and the shear stress at the pipe wall.

Answer:
Given:
From Q1: $Q = 0.002988\ \mathrm{m}^3/\mathrm{s}$

$$D = 0.05\ \mathrm{m}$$
$$L = 15\ \mathrm{mm} = 0.015\ \mathrm{m}$$
$$\mu = 0.035\ \mathrm{Pa\cdot s}$$
$$\rho = 920\ \mathrm{kg/m^3}$$

To Find: ΔP, max velocity u_{max}, wall shear stress τ_w
Solution:
$V = \frac{Q}{A} = \frac{0.002988}{0.0019635} = 1.5217\ \mathrm{m/s}$ (same as above)

$$\Delta P = \frac{128\mu LQ}{\pi D^4} = \frac{128 \times 0.035 \times 0.015 \times 0.002988}{\pi \times (0.05)^4}$$

Num $= 128 \times 0.035 \times 0.015 \times 0.002988 = 128 \times 1.5687 \times 10^{-6} = 0.0002008$

Denom = $\pi \times 6.25 \times 10^{-6} = 1.9635 \times 10^{-5}$

$$\Delta P = \frac{0.0002008}{1.9635 \times 10^{-5}} = 10.23\ \mathrm{Pa}$$
$$u_{max} = 2V = 3.0434\ \mathrm{m/s}$$
$$\tau_w = \frac{\Delta P \cdot D}{4L} = \frac{10.23 \times 0.05}{4 \times 0.015} = \frac{0.5115}{0.06} = 8.525\ \mathrm{Pa}$$

Final Answer:

$$\boxed{\Delta P = 10.23\ \mathrm{Pa}, u_{max} = 3.04\ \mathrm{m/s}, \tau_w = 8.53\ \mathrm{Pa}}$$

Q-3: Darcy-Weisbach & Friction: Water flows through a rough pipe of diameter 400 mm and length 2500 m at a rate of 0.4 m3/s. If the kinematic viscosity of water is 1 x 10-6 m2/s and the absolute roughness is 0.05 mm, use the Moody diagram concept (or Colebrook equation) to find the friction factor and subsequently calculate the major head loss.

Answer:
Given:
$D = 0.4\ \mathrm{m}$, $L = 2500\ \mathrm{m}$

$$Q = 0.4\ \mathrm{m}^3/\mathrm{s}$$
$$\nu = 1 \times 10^{-6}\ \mathrm{m}^2/\mathrm{s}$$

Absolute roughness $\varepsilon = 0.05\ \mathrm{mm} = 5 \times 10^{-5}\ \mathrm{m}$
To Find: Friction factor f, major head loss h_f
Solution:

$$V = \frac{Q}{A} = \frac{0.4}{\pi/4 \times (0.4)^2} = \frac{0.4}{0.12566} = 3.183\ \mathrm{m/s}$$
$$Re = \frac{VD}{\nu} = \frac{3.183 \times 0.4}{1 \times 10^{-6}} = 1.273 \times 10^6$$

Relative roughness $\varepsilon/D = \frac{5\times10^{-5}}{0.4} = 1.25 \times 10^{-4}$

From Moody chart for $Re = 1.27 \times 10^6$, $\varepsilon/D = 0.000125$:
$f \approx 0.014$ (smooth pipe zone?) Check Colebrook: For such low roughness, f close to smooth pipe: $f = 0.012$ to 0.014. Let's take $f = 0.013$.

$$h_f = f\frac{L}{D}\frac{V^2}{2g} = 0.013 \times \frac{2500}{0.4} \times \frac{(3.183)^2}{2 \times 9.81}$$
$$= 0.013 \times 6250 \times \frac{10.13}{19.62} = 0.013 \times 6250 \times 0.5165$$
$$= 0.013 \times 3228 = 41.96 \text{ m of water}$$

Final Answer:

$$\boxed{f \approx 0.013, h_f \approx 42.0 \text{ m}}$$

Q-4: Minor Losses: An engine cooling system features a sudden expansion in a pipe from 50 mm to 100 mm diameter. If the flow rate of the coolant is 12 lps, calculate the head loss due to the sudden expansion.

Answer:
Given:

$$D_1 = 50 \text{ mm} = 0.05 \text{ m}$$
$$D_2 = 100 \text{ mm} = 0.1 \text{ m}$$
$$Q = 12 \text{ lps} = 0.012 \text{ m}^3/\text{s}$$

Water: $\rho = 1000$
To Find: Head loss h_L
Formula:
$h_L = \frac{(V_1 - V_2)^2}{2g}$ or $h_L = K\frac{V_1^2}{2g}$ with $K = \left(1 - \frac{A_1}{A_2}\right)^2$
Solution:
$A_1 = 0.0019635 \text{ m}^2$, $A_2 = 0.007854 \text{ m}^2$

$$V_1 = 0.012/0.0019635 = 6.112 \text{ m/s}$$
$$V_2 = 0.012/0.007854 = 1.528 \text{ m/s}$$
$$h_L = \frac{(6.112 - 1.528)^2}{2 \times 9.81} = \frac{(4.584)^2}{19.62} = \frac{21.01}{19.62} = 1.071 \text{ m}$$

Final Answer:

$$\boxed{h_L = 1.07 \text{ m}}$$

Q-5: Pipes in Series & Parallel: Two pipes of lengths 1000 m and 800 m, and diameters 300 mm and 200 mm respectively, are connected in series. Find the diameter of an equivalent pipe of length 1800 m that will carry the same discharge for the same total head loss.

Answer:
Given:
Pipe 1: $L_1 = 1000$ m, $D_1 = 0.3$ m
Pipe 2: $L_2 = 800$ m, $D_2 = 0.2$ m
Series connection.
Equivalent pipe: $L_e = 1800$ m, find D_e
Formula (Darcy-Weisbach, same f for all pipes):

$h_f = h_{f1} + h_{f2} \rightarrow \frac{fL_eQ^2}{12.1D_e^5} = \frac{fL_1Q^2}{12.1D_1^5} + \frac{fL_2Q^2}{12.1D_2^5}$
Cancel common terms:

$$\frac{L_e}{D_e^5} = \frac{L_1}{D_1^5} + \frac{L_2}{D_2^5}$$

Solution:

$$\frac{1800}{D_e^5} = \frac{1000}{(0.3)^5} + \frac{800}{(0.2)^5}$$

$(0.3)^5 = 0.00243$, $(0.2)^5 = 0.00032$

$$\frac{1000}{0.00243} = 411522, \frac{800}{0.00032} = 2.5 \times 10^6$$

Sum = 2,911,522

$$D_e^5 = \frac{1800}{2911522} = 0.0006183$$

$$D_e = (0.0006183)^{1/5} = (6.183 \times 10^{-4})^{0.2}$$

Let's calculate: $\log D_e = \frac{1}{5}(\log 6.183 \times 10^{-4}) = \frac{1}{5}(0.7912 - 4) = \frac{1}{5}(-3.2088) = -0.64176$

$$D_e = 10^{-0.64176} = 0.228 \text{ m} \approx 228 \text{ mm}$$

Final Answer:

$$\boxed{D_e = 228 \text{ mm}}$$